Results & Lessons Learned from Performance Testing of Humans in Spacesuits in Simulated Reduced Gravity

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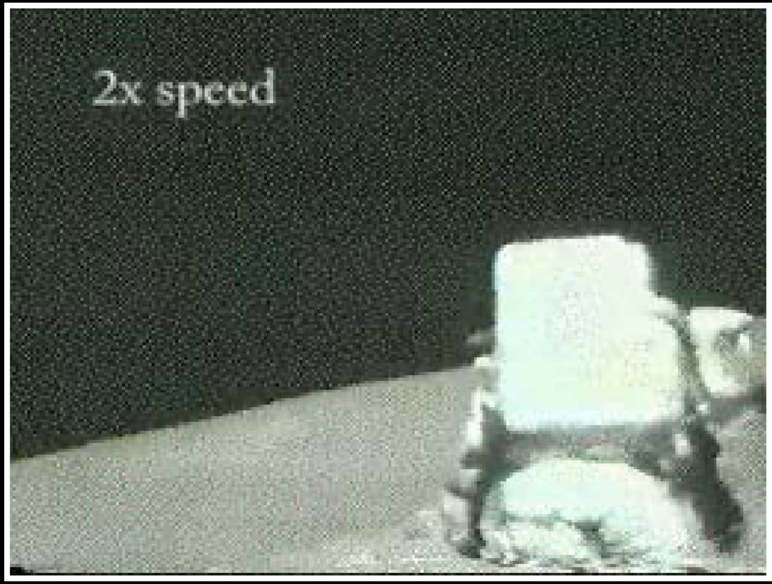
EPSP Project Overview

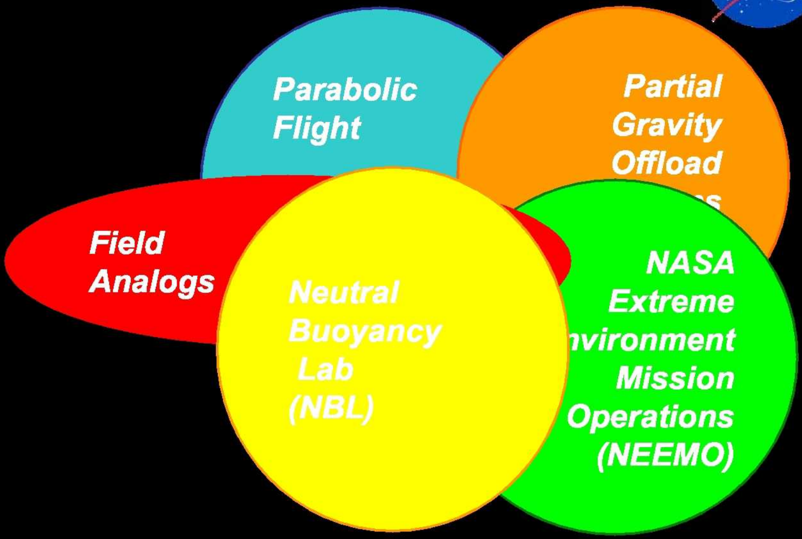
- The Apollo lunar EVA experience revealed challenges with suit stability and control
  - Likely a combination of mass, mobility, and center of gravity (CG) factors
- The EVA Physiology, Systems and Performance (EPSP) Project is systematically working with other NASA projects, labs, & facilities to lead a series of studies to understand the role of suit mass, weight, CG, and other parameters on astronaut performance in partial gravity environments



Apollo 17
Extravehicular Activity (EVA)

Testing in Analog Environments

- Tests are performed in multiple analogs, as each environment has limitations for simulating partial gravity and representing a realistic operational environment



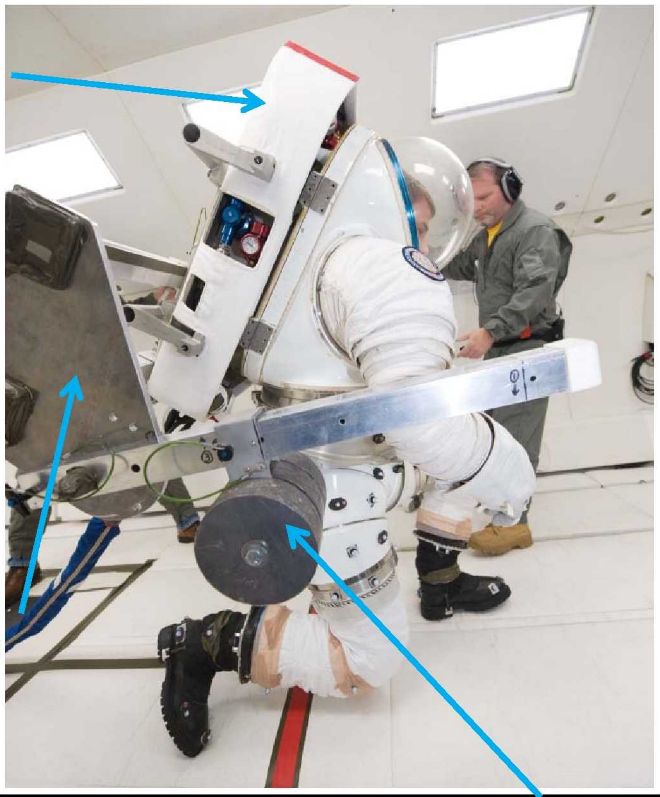
Objectives

1. Determine if and how the following factors affect human performance during ambulation and lunar exploration tasks in partial gravity:
   – Mass
   – Weight / gravity level
   – CG

2. To define the usability and limitations of partial gravity analogs for EVA applications
   – Partial gravity offload systems
   – Parabolic flight

Methods

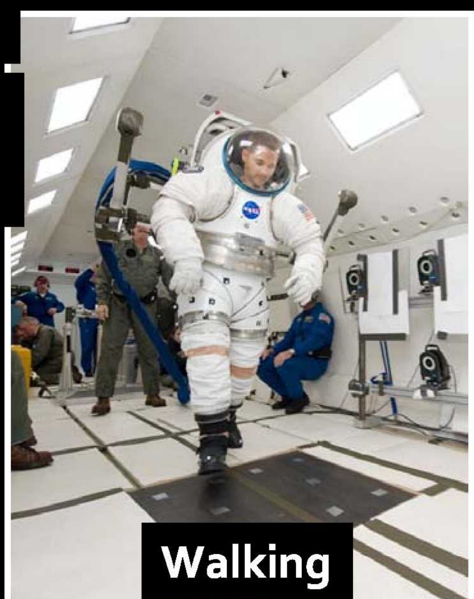
- Custom weight support structure interfaced to prototype lunar spacesuit
  - Allowed manipulation of both suit mass and CG
- Utilized NASA C-9 parabolic flight aircraft
  - 14 flights, ~60 parabolas/flight (~840 total parabolas)
- Designed to compare to ground-based testing or fill gaps due to limitations in other analogs (i.e. insufficient lift capacity, limited degrees of freedom)



Methods (continued)

- Three series of tests were executed
  - Varied weight (0.1-g, 0.17-g, 0.3-g; 120 kg suit mass; constant CG)
  - Varied mass (89, 120, & 181 kg suit mass; 0.17-g; constant CG)
  - Varied CG (B=4.8/1.0, C=7.6/14.4, and P=11.2/20.1 cm, aft/above the reference subject's CG; 181 kg constant suit mass ; constant 0.17-g)

- Suit pressurized to 29.6 kPa
- Six subjects (80.0±10.6 kg, 182.3±6.2 cm) completed 4 tasks


Walking


Kneel/Stand


Shoveling


Rock Pickup

Methods (continued)

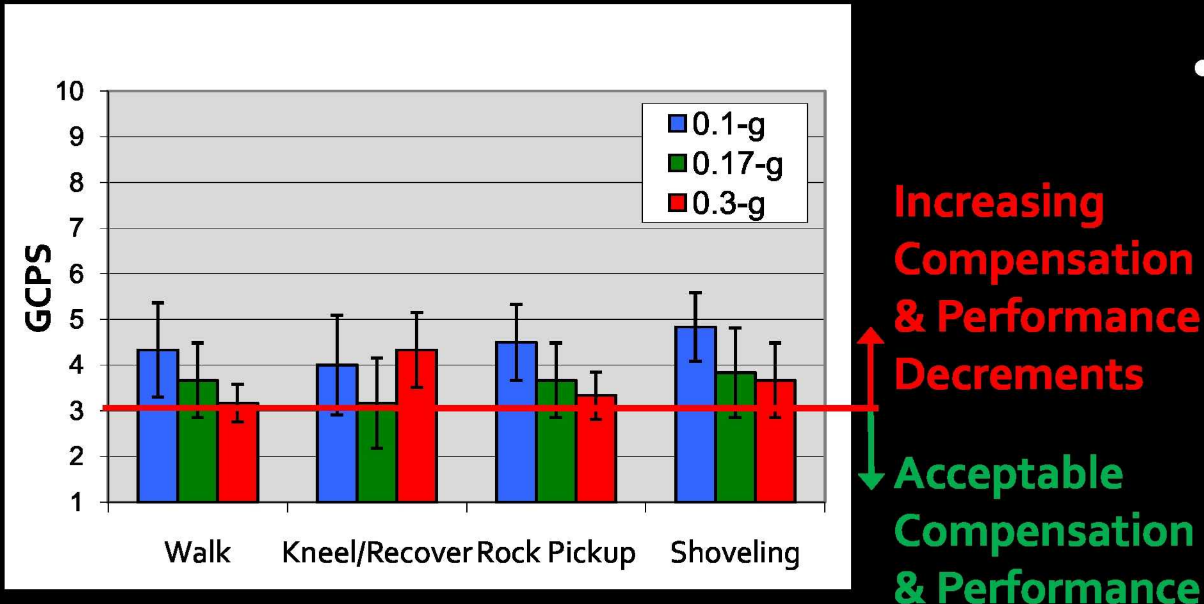
- Walking was over ground as a treadmill could not be accommodated for suited testing due to height limitations

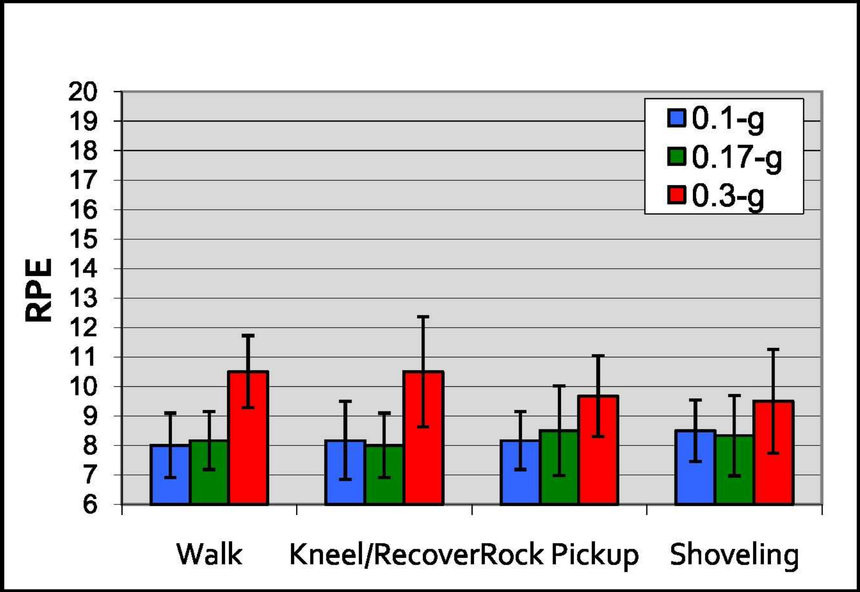
- Ratings of perceived exertion (RPE) and gravity compensation and performance scale (GCPS) ratings were collected
  - GCPS ratings are based on the level of operator compensation required in partial gravity compared to performing the same task, unsuited, in 1-g
  - On this scale, a rating of 2 is equal to 1-g performance and larger numbers indicate perceived increases in the amount of subject compensation required to achieve desired performance

- Motion-capture cameras were used to capture kinematic data, and force plates were used to record ground reaction forces for all tasks except kneel/stand.

Example of Rock Pickup Task

Results: Varied Weight

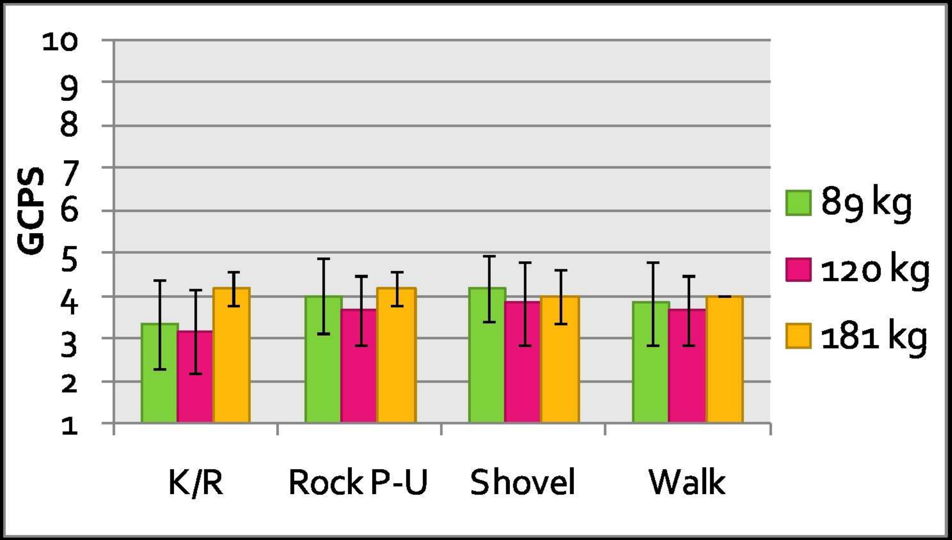




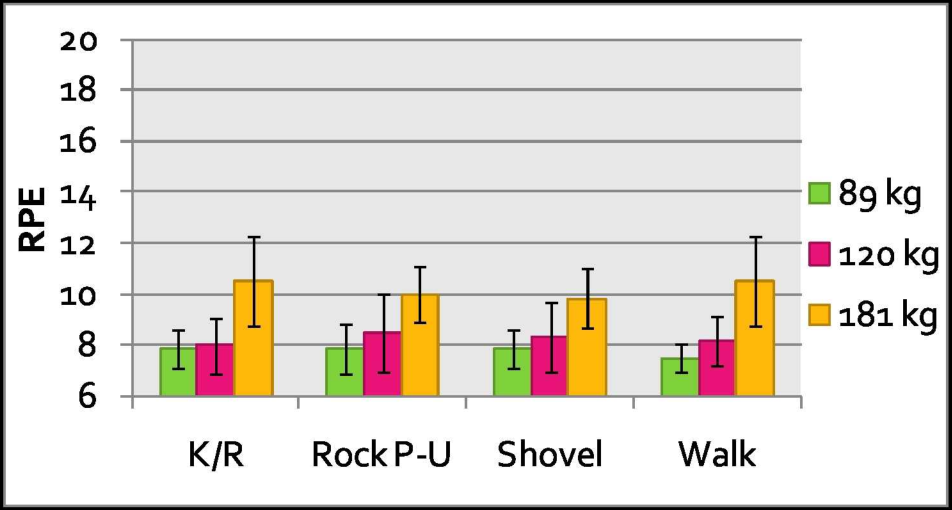
- In general, GCPS ratings were higher for 0.1-g, indicating more compensation was needed to achieve performance
- RPE was highest at 0.3-g, as expected as subjects are supporting more weight while performing tasks

Results: Varied Mass

- GCPS ratings show little variation, however subject's comments indicated the greater the mass the more they could feel its effects

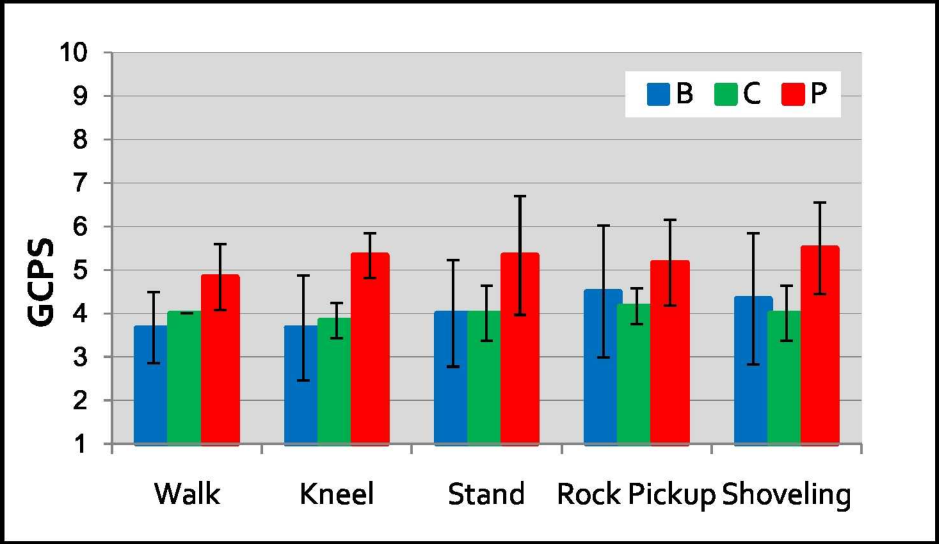


- RPE was highest at the greatest mass, which is consistent with the varied weight results

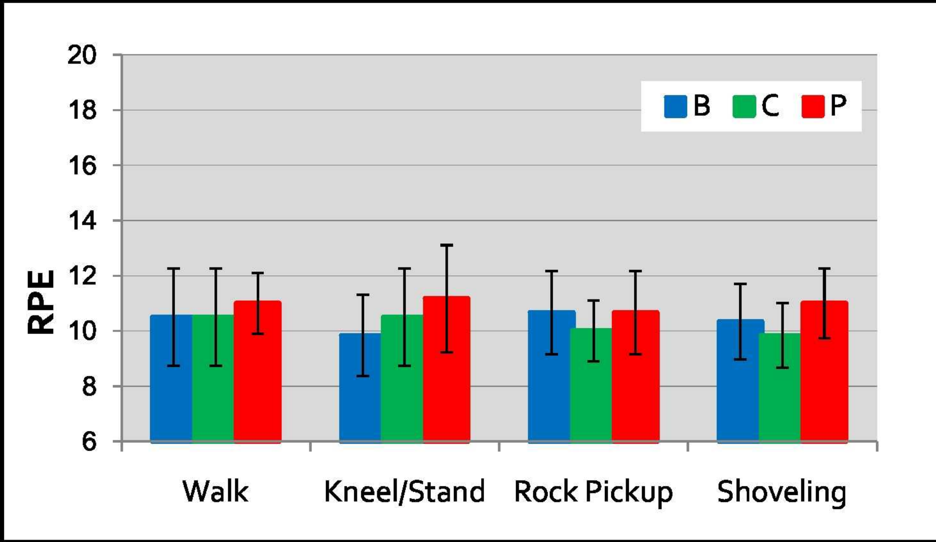


Results: Varied Center of Gravity

- GCPS highest for the "P" CG with subjects commenting they felt the most unstable ("P" was the most high/aft)
- Large variability across subjects (GCPS 3-7)

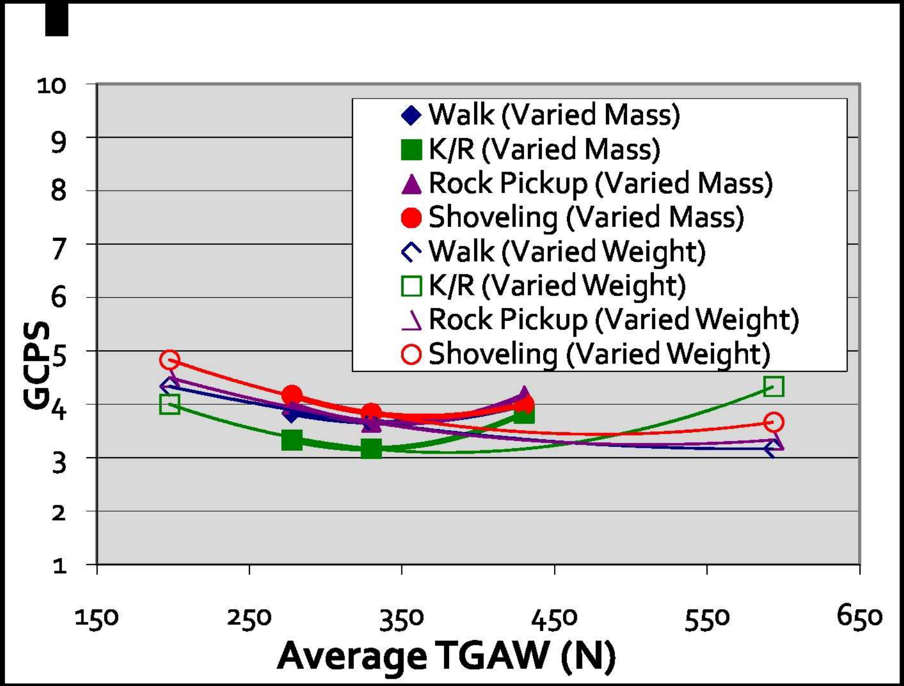


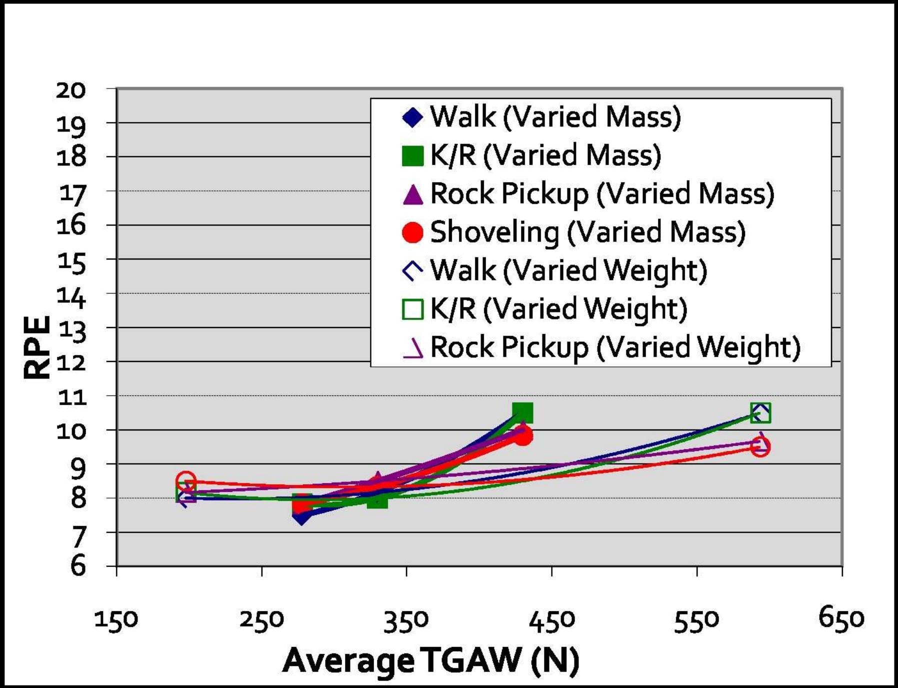
- RPE ratings across CG showed only subtle differences
- Compensations less "mental", more physical



Discussion

- Can compare ratings vs. total gravity adjusted weight (TGAW) produced by varied mass and varied weight
- GCPS similar at low TGAW but varied mass trends upward at higher TGAW
- RPE increase more quickly at higher TGAW for varied mass





Discussion

- Modeling a change in suit mass by altering weight (i.e. gravity level or offload) may be an adequate simulation for a limited range when looking at gross metrics of human performance

- Modifying CG during suited testing at lunar gravity seems to affect subjective performance ratings

- Inter-subject variation in performance ratings indicate further study is needed to evaluate the interactions among
  - Lunar gravity simulation technique
  - System CG
  - System mass
  - Subject characteristics such as anthropometry, strength, and fitness

Discussion

- Ability to compare results from parabolic flight with those from ground-based tests was limited
  - Differences in experiment setup, test points, & subject populations
  - Design ground-based protocols with parabolic light in mind to be able to do direct comparison later

- Kinematic & ground reaction force data were highly variable due to volumetric limitations and variability of the acceleration levels during a parabola
  - Subjects unable to attain a stable gait due to the need to stop, turn, & start in the confined space
  - "Targeting" of measurement equipment and motion capture volumes likely affected results
  - Acceleration variation made it difficult to discern differences in ground reaction forces vs. aircraft-induced disturbances

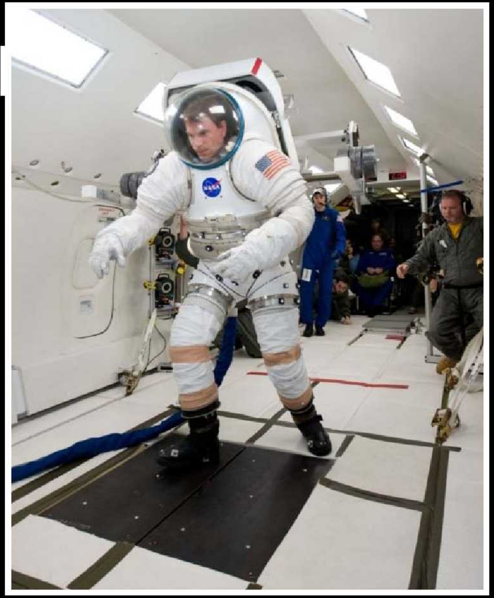
Example of Ambulation Task

Click Here

Conclusions

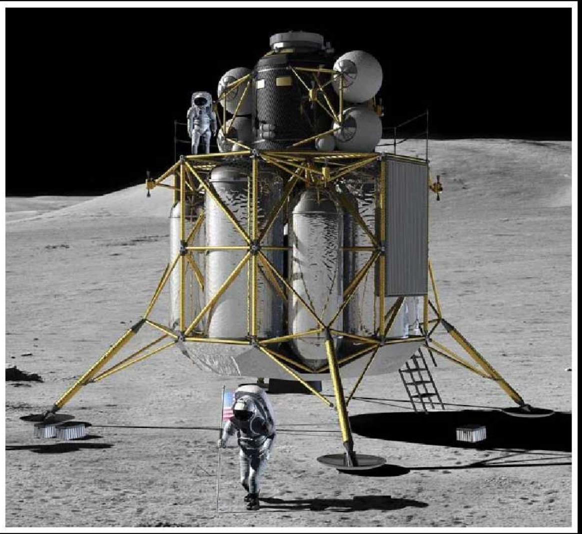
- Parabolic flight can provide the most realistic simulation of reduced gravity for suited human testing
- Limitations of the test environment can affect the quality of the data collected
  - Short duration of parabolas
  - Cabin dimensions
  - Acceleration variability
- What can be done to improve?
  - Aircraft and experienced aircrews to provide max duration parabolas and the greatest accuracy
  - Maximize the length and height of the cabin for ambulation or inclusion of a treadmill
  - Identical design of experiments across environments to increase comparability
  - Keep costs reasonable to allow for larger numbers of subjects and repetitions

Apollo



Analog Testing of Prototype Systems

Improved Spacesuits



Lunar Return

Questions?

Thank You